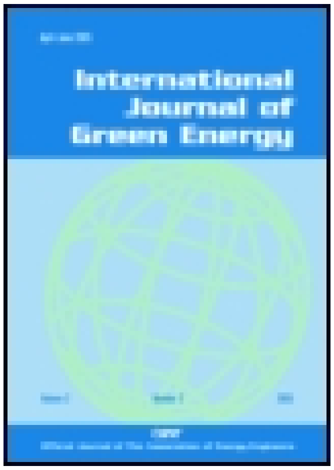

International Journal of Green Energy
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ljge20

Solar oven with downward and upward solar gain for children's dining rooms in developing countries

Alfredo Esteves[a], Viviana Noelia Quiroga[a], Guadalupe Cuitiño Rosales[a] & Fernando Buenanueva[a]

[a] Laboratorio de Ambiente Humano y Vivienda (LAHV-INCIHUSA-CONICET) Centro Científico Tecnológico (CCT CONICET Mendoza) Avenida Ruiz Leal s/n - Parque General San Martín C.C. 131 - 5500 Mendoza - Argentina

Accepted author version posted online: 16 May 2014.

Solar oven with downward and upward solar gain for children's dining rooms in developing countries

Alfredo Esteves[1a*], Viviana Noelia Quiroga[a], Guadalupe Cuitiño Rosales[a], Fernando Buenanueva[a]

[1] Currently Regular CONICET Researcher.

[a] Laboratorio de Ambiente Humano y Vivienda (LAHV-INCIHUSA-CONICET) Centro Científico Tecnológico (CCT CONICET Mendoza) Avenida Ruiz Leal s/n – Parque General San Martín C.C. 131 – 5500 Mendoza – Argentina

* Corresponding autor Tel.: 0054 261 5244309 – Fax: 0054 261 5244001

E-mail adress: aesteves@mendoza-conicet.gov.ar

ABSTRACT:

In Argentina there exist children's dining rooms where infants and their mothers take lunch at noon and glasses of milk in the afternoon. These dining rooms are established in rural or marginal urban areas. Solar ovens are an interesting option for cooking with less expense of money, and they diminish environmental impact in these zones. A solar oven with downward and upward solar gain was built and tested. Upward solar gain is through Fresnel reflectors. The use of Fresnel reflectors resulted in higher heating power as compared to a solar oven with upper reflectors only. The performance with different numbers of Fresnel units was compared with a single-reflector solar oven with no lower Fresnel reflectors. Oven power was analysed and the

ACCEPTED MANUSCRIPT

result indicates that power grows as the number of Fresnel reflectors increases: it grows by 55% using 3 to 9 Fresnel reflectors, and by 34.6% with 3 to 6 Fresnel reflectors. These values are enough to cook several rations of food, and make this oven appropriate for use in dining rooms in developing countries.

Keywords: Solar oven cooker, Fresnel reflector, Thermal performance test, Children's dining rooms, Developing countries.

Symbols and units

Mw mass of water (kg)

Cw specific heat capacity of water (kJ/kg ºC)

ΔT rise in water temperature (ºC)

Ta ambient temperature (ºC)

Tw water temperature (ºC)

Δτ time interval (sec)

Pu usable thermal power (W)

Ac collector area (m^2)

Gt solar irradiation (W/m^2)

η thermal efficiency

Pst standard thermal power (W)

INTRODUCTION

A number of different solar energy methods are available to provide the temperatures required for cooking and baking. One of the simplest things is taking a thermal insulated box with single or double glass on one of its sides for the passage of solar radiation. In a clear day, baking temperatures of near 120-140ºC can be reached inside that box by reorienting the reflectors to the sun every 15 minutes. This type of solar cooker is practical due to their inherent simplicity and lower cost. Furthermore, the food is physically protected from contamination.

There are however some disadvantages, as there is the possibility of food spillage during tracking; solar heat is applied to the lid of the pot at high solar altitudes, and not to its sides or bottom and, in addition, condensation of vapours on the oven glazing reduces transmissivity during later stages of cooking.

Yet, there are several important advantages in terms of technology transfer to community people: a) ease of operation – this cooker can be redirected to the sun by the children in the house and can work without control for several hours (3 or 4); b) ease of construction with locally available skills and materials; c) it offers more security than concentrating cookers and d) it is a very simple device (Esteves et al. 1999). Figure 1 shows a Nandwani oven (Nandwani 1993), this model was built by people of RICSA (Ibero-American Network of Solar Food Cooking) in order to meet the terms of the solar oven test protocol (Esteves 2003). This solar family oven is generally applied to cooking for 4-5 people.

ACCEPTED MANUSCRIPT

The box solar oven has been built, and even mass-produced, in several countries of Latin America (Serrano and Collares Pereira 2003). Nandwani (2007) combines different gadgets in a solar oven named food processor which is used to cook meals, heat and pasteurize water, dry agricultural products and distillate liquids. Figure 1 shows a Nandwani solar oven with one reflector.

A single solar family oven is very limited for preparing food for groups of 15 or 20 people. In Argentina there are children's dining rooms where infants and their mothers take lunch at noon and glasses of milk in the afternoon. These dining rooms are established in rural or marginal urban areas. They spend a lot of fuel (liquefied gas) for cooking. Increasing awareness of the growing global need for alternative cooking fuels has resulted in an expansion of solar cooker research and development. Solar ovens are an interesting option for cooking with less expense of money, and they diminish environmental impact in rural zones (Esteves 1999).

In developing countries, there are three alternatives regarding energy-efficient cooking or solar cooking applied to preparing 15 to 20 rations of food:

- Cooking with 4 or 5 solar family ovens.
- Cooking with a heat-retaining cooking box.
- Cooking in powered solar cookers.

Cooking with several solar family ovens is the case of the Solar Restaurant of Villaseca in the IV Region of Chile, a rural town in a desert zone. Figure 2 shows several solar family ovens to cook different types and numbers of meals. They prepare a lot of food to be sold at the solar restaurant. This restaurant is included in the tourist tour route.

ACCEPTED MANUSCRIPT

To cook with a heat-retaining cooking box, it is necessary to heat the food until boiling point. Once the food is heated to boiling, it has the necessary energy it requires to cook. It is necessary to retain this energy in the food. In a heat-retaining cooking box, the process is first heating the food to boiling in a gas cooker and then placing it in an insulated box in order to continue the cooking process (Mercado and Esteves 2004; Sindelar and Radabaugh 2008).

Powered solar cookers have been developed in several countries. One method for cooking in these conditions is through the use of a concentrator which can be a dish covered with reflecting surfaces, such as a mirror, which will concentrate the solar radiation falling upon it onto a container which holds the food to be heated or cooked. The attempt to shorten solar cooking times to near accustomed levels resulted in concentrating cookers and hence the need to track the sun more frequently. Franco (2004) developed a solar concentrator combined with boiler for producing steam at atmospheric pressure. This steam is transported through a flexible pipeline to the cooking pot, where it is made to bubble directly in the liquid being heated. Another possibility is directly placing the pot on the concentrator focus.

Shukla (2009) has been studied solar community and domestic type parabolic. The results show that the community-size solar cooker has high energy efficiency, high exergy efficiency, and low characteristic boiling time as compared to domestic size solar cooker.

Schwarzer and Vieira da Silva (2003) have reported a solar cooking system with two separate basic components: solar flat plate collectors with reflectors and a cooking unit. The working fluid, usually a vegetable oil, circulates in natural thermo-siphon flow through a copper piping that connects the components. This system presents interesting features such as the possibility of indoor and night cooking. This prototype installed in the city of Jülich, Germany, has been tested. A temperature of 220ºC was measured for a 2 m^2 collector area system, for solar radiation of 1000 W/m2 and 25ºC ambient temperature. These papers refer mainly to the preparation of moist meals.

ACCEPTED MANUSCRIPT

Ekechukwu and Ugwuoke (2003) presents the performance of a flat plate reflector augmented box-type solar energy cooker. Maximum absorber plate and chamber air temperatures of 138ºC and 123ºC respectively were recorded with the reflector in place at 13 hr local time and a solar insolation of 920 W/m^2. The maximum absorber plate temperature without reflector was 119ºC for a solar insolation of 930 W/m^2. These results indicate that a better solar cooker performance is achieved using reflectors.

Quiroga and Saravia (2004) indicate that improvement with a reflector placed on the south-facing edge of the solar oven (in southern localities) depends on the time of the year. Solar energy gain improved by 51% in winter and by 29% in summer. These values are for Salta, Argentina at 24.5º south latitude.

Nahar (2001) reports a design with double upper reflector to improve solar energy gain and with a 4-mm thick layer of transparent insulation material between two 4-mm thick glass panes to minimise convective heat losses through the window. The device consists of a double-walled hot box of aluminium with 50 mm of glass wool on the walls and 80 mm on the bottom. Two flat mirror reflectors are fixed on the oven. A two-reflector solar cooker was tested, with one reflector facing east and the other facing the equator in the forenoon, and one facing the equator and the other facing west in the afternoon. This ensures 180 min of work without sun-tracking. The surface area of the absorber plate is 0.16 m^2. The cooker weighs 20 kg. A single-reflector solar cooker was tested first. Its stagnation temperature was 125ºC. In the cooker with polycarbonate honeycomb and double reflector, stagnation temperature of the absorber plate rose to near 160ºC.

Kurt et al. (2008) has studied the shape of box in performance of solar oven. The cylindrical shape provided high thermal performance, which is indicated by high thermal efficiency and low characteristic boiling time, in comparison with the rectangular shape. Öztürk (2004) has been studied a Solar Box Cooker (SBC) in comparison with Solar Parabolic Cooker (SPC). The energy output at a temperature difference between water and ambient of 50K was estimated to be 11.00% and 30.72% for the SBC and SPC, respectively.

Khalifa et al. (1987) developed a new solar oven cooker with spiral concentrator that permits heating from the bottom and sides. He used a commercial pressure cooker painted with a high solar absorptance and high temperature paint, and reported for 4.3 kg of chicken, potatoes and tomato paste which took less than 3 hours to cook. Khalifa indicates that 6 kg of water was brought to boil in 3 hours and 20 minutes and that this solar oven has the possibility to reach temperatures up to 180ºC, so that cooking operations such as grilling, frying and baking are feasible with such cooker.

Esteves et al. (2006) describe a new solar oven with downward and upward solar gain, with small windows and several flat reflectors similar to Fresnel reflectors, called DG Solar Oven (Double Gain Solar Oven). This solar oven permits cooking several rations (15-20) and is appropriate for use in children's dining rooms, for example cooking 9 kg of meat in 2 hr with a solar insolation of 850W/m^2.

In this paper a DG Solar Oven with 3, 6 and 9 lower mirrors in Fresnel reflector has been studied in order to know if thermal performance (stagnation temperature and cooking power) is appropriate for use in children´s dining room.

BRIEF SOLAR OVEN DESCRIPTION

The DG Solar Oven consists of a hot box with double wall of painted MDF (Medium Density Fiberboard) 12 mm in thickness for the exterior side, and a 3 mm-thick rigid cardboard for the inner side. Wool insulation (0.06 m thick and 15 kg/m3 in density) is inserted between them as thermal insulation to reduce conduction heat losses from the interior to the exterior of the cooker.

ACCEPTED MANUSCRIPT

Outer dimensions of the box are 1.15 m x 0.65 m x 0.34 m; and inner dimensions 1.00 m x 0.50 m x 0.139 m. A schematic drawing of the cooker is shown in Figure 3a.

The interior of the oven has an aluminium sheet (0.5 mm thickness) for better clean-up. The solar oven has two windows, one of 0.45 m x 1.00 m in the upper part of the cooker chamber with two glasses (0.04 mm thick and separated by 0.02 m), and a small window of 0.13 m x 1.00 m at the bottom to improve solar gain into the cooker chamber from nine lower reflectors of 1.00 x 0.10 m. As shown in Figure 3b.

The upper window has a plane reflector similar to a solar family oven. This reflector improves solar gain through the upper window when open. When closed, it has have two advantages: it maintains high temperatures inside the cooker chamber, for example, to keep the meal hot for 3 hr. (when the food is ready in the afternoon), and protects the window glasses when the cooker is not working.

Nine reflectors (lower mirrors) each measuring 1.00 m x 0.100 m x 0.0032 m thickness are mounted at 1.10 m from the bottom of the box and 0.15 m from the ground. The nine reflectors are mounted one close to the other so as to form a plane and not to shadow one another. The orientation of all the reflectors can be adjusted at the same time by raising one end (point A in Figure 3a) of the whole plane, thus changing the plane tilt in agreement with the changes in solar altitude. Figure 4 shows a picture of the DG Solar Oven. Figure 5 shows the bottom window and a Fresnel concentrator with 9 (nine) solar reflectors.

DG Solar Oven has the following characteristics:

Upper window: 0.45 x 1.00 m.

Lower window: 0.13 x 1.00 m.

Solar absorber plate: two plates of 0.50 m x 0.45 m.

Cooking chamber: 1.00 m x 0.50 m x 0.139 m = 0.069 m^3 = 69 dm^3

Measures of solar oven at work: height: 2.00 m; width = 1.15 m; depth = 1.50 m.

Upper reflector: 1.14 m x 0.65 m.

Lower Specular reflectors: 9 (nine) reflectors of 1.00 m x 0.10 m x 0.0032 mm.

Door: 0.16 m x 0.99 m

The DG Solar Oven works using the basic principle: solar energy is converted to thermal energy that is retained for cooking. The cooker chamber has upper and lower windows (See Fig 3a) and requires frequent tracking. The tracking is two ways it is necessary to rotate the oven (which adjust the azimuth variation) and move angular position of reflectors (which adjust the variation in solar altitude), to maintain solar energy collected at appropriate intensity. These adjustments must be made every 15/20 minutes.

Solar energy that`s transmitted through the upper window is enhanced by reflector and strike over absorber plate (or in the pot) transforming solar energy into heat. In Addition, solar energy which is reflected in lower mirrors of Fresnel reflector strike over lower window and it is transmitted to the absorber plate.

Both amounts of energy, from the top and bottom generate high temperature on absorber plate and is transmitted by conduction to the pot in order to cook the food. The time taken for cooking depends on the type and load of food.

ACCEPTED MANUSCRIPT

The DG solar oven permits cooking larger amounts of food due to its higher solar energy gain.

Thermal performance test

Two thermal tests were made, one for stagnation temperature of the absorber plate (no-load test) and another one for thermal power and efficiency of the solar oven with Funk procedure (Funk 2000) with a variable number of lower plane mirrors.

Climatic conditions records

Absorber plate temperatures were measured with the aid of chromel alumel thermocouples (Type K) with sensor 0-500ºC and recorded by a Hobo data logger. Data on ambient temperature and wind velocity and direction were recorded with a Davis Vantage Pro weather station every 15 minutes. Solar Radiation was measured with a CM5 Kipp and Zonen Solarimeter.

Water temperature was measured with copper-constantan thermocouples and recorded by a Hobo data logger.

No-load test

A single solar measure of a solar cooker's performance is stagnation temperature of absorber plate under no-load condition at some quasi steady state. At this state, the absorber plate temperature is highest. This temperature indicates the capacity of the solar oven to bake and roast.

Absorber plate stagnation, ambient temperature and solar radiation were measured and recorded every 2.5 minutes.

ACCEPTED MANUSCRIPT

Maximum and minimum solar radiation, ambient temperature and maximum stagnation temperature for each case are indicated in Table 1 for the three days when the test was carried out.

Absorber plate stagnation temperatures measured without load are shown in Figure 6. It is clear that the oven with 9 low Fresnel reflectors reaches the highest absorber plate temperature (185.2ºC). But it is possible to see that there is little difference between maximum stagnation temperatures obtained with 6 and 9 reflectors, only 5.8ºC.

Figure 6 shows a smooth temperature rise in the Nandwani oven, whereas the double gain solar oven shows more temperature variability which results from the low reflectors being reoriented to the sun every 15 minutes.

The temperatures obtained with 6 and 9 lower reflectors are higher than that presented by Ekechukwu and Ugwuoke (2003) of 138ºC and than that reported by Nahar (2001) of 160ºC for a box with double reflector and also polycarbonate honeycomb. Khalifa et al. (1987) indicated a stagnation temperature close to 180ºC in a new solar oven with spiral concentrator.

Thermal power test

A cooking utensil containing 6 kg of water was kept inside the cooking chamber of the solar oven at 11 hr solar time and rise in water temperatures was measured. The time required for reaching water temperatures of 90 ºC and to boiling point was measured as well.

A record was kept of data on water temperatures between 40 and 90ºC in order to obtain performance data for humid cooking. There is some flexibility in the choice of initial water temperature T_{w1}. Values of $T_{w1}>T_a$ are recommended (Funk 2000; Esteves 2003). The upper part of the temperature interval must be lower than the boiling point since considerable error can be introduced in the temperature of water near the boiling point. Cooker thermal power was assessed with Funk method (Funk 2000).

The cooker thermal power represents the rate of sensible energy used to heat up a certain mass of water in a given time interval. Thermal power of the solar oven is expressed by Equation (1):

$$Pu = \frac{Mw.Cw.\Delta T}{\Delta \tau} \qquad (1)$$

The thermal power of solar cookers for each time interval was set to a standard insolation of 700 W/m^2 by multiplying cooking power by 700 W/m^2 and dividing by the average solar insolation recorded during the corresponding interval (Funk 2000).

$$Pst = \frac{Pu.700}{\overline{Gt}} \qquad (2)$$

The oven with high collector area had a high initial cooking power. The slope of the cooking power regression line correlates to the heat loss coefficient independent of the solar intercept area (Funk 2000). The coefficient of determination (R^2) must be higher than 75% to satisfy the standard in all cases.

Thermal efficiency is determined as the energy used in heating the mass of water (Mw) divided by the incident solar flux on the collector plane (Gt) integrated with respect to time multiplied by the collector area (Ac). It is expressed as Equation (3) shows:

$$\eta = \frac{Mw.Cw.\Delta T}{Ac.\int Gt.d\tau} \qquad (3)$$

RESULTS

Climate data during the tests were recorded and are indicated in Table 2.

Figure 7 show water temperatures in the oven, ambient temperature and solar radiation during the test to heat 6 kg of water with 9, 6 and 3 low Fresnel reflectors. Nandwani oven power test was made with 3.6 kg of water according to its smaller collector area. Figure 7 show thermal power standardized by Funk method (Equation 1 and 2) for DG Solar Oven with 3, 6, or 9 lower reflectors.

The solar oven with largest collector area has the highest y-intercept (initial cooking power) and a high heat loss coefficient, and all three ovens have negative slope. The slope of the cooking power regression line correlates to the heat loss of the oven. Funk (2000) has compared several solar cookers; DG Solar Oven is ranked as “Large area, good insulation” type. The coefficient of determination (R2) values exceeded 0.85 (satisfying the standard) for all but one cooker.

Single measure of performance: the value for standardized cooking power (W) is to be computed for a temperature difference (tw-ta) of 50ºC using the above determined relationship. This paper provides consumers with a useful tool for comparison and selection, and values are presented in Table 3. It is possible to see very high cooking power in all cases compared with Nandwani solar oven (Esteves 2003).

The cooking power of DG Solar Oven at temperature differences of 50ºC was estimated as 299.2 W, 259.2 W and 192.7W with 9, 6 or 3 lower reflectors.

The best performance of box-type solar cookers was achieved with the largest cooker load. Cooker Model II boiled 1 kg of water in 15 min (aperture area equals 1 m^2) with a daily efficiency of 26.7% (El-Sebaii and Ibrahim 2005). Table 3 indicates the thermal efficiency of the solar oven with 3, 6 or 9 lower Fresnel reflectors. It is evident that thermal efficiency is between 24% and 27%, typical values for this type of solar ovens.

The high stagnation temperature and thermal power achieved by these solar cookers make it possible to cook several rations of food, which renders them interesting for use in children's dining rooms in developing countries.

Figure 8 indicates the meals most frequently eaten in children's dining rooms. With a little more than 1.5 hr in boiling water, all boiled food (soup, rice, ravioli, pot roast meat, stew, vermicelli) can be cooked 3-4 times in the day, up to 20 rations.

With temperatures of 185.2ºC (no-load test) it is possible to bake all kind of food: cakes, 'milanesas' (breaded steak), roast chicken, bread of meat, stuffed potatoes, roast meat, crème caramel, pie of potatoes, pizzas. Figure 9 shows a whole piece of roast goat meat that fits inside the cooker chamber and some bread as examples of the food that can be prepared in a DG Solar Oven.

CONCLUSION

The thermal performance (stagnation temperature and thermal power test) of DG Solar Oven has been studied. Stagnation temperatures measured without load are 185.2ºC, 179.4ºC, 142.2ºC for 9, 6 and 3 lower mirror in Fresnel reflectors and cooking power for the same cases results as: 299.2W, 259.2W and 192.7W respectively.

The operation with 6 Fresnel reflectors yielded few differences with 9 Fresnel reflectors in stagnation temperature and thermal power. It is possible to work with 6 reflectors to make the oven a more economically feasible option.

This work shows a significant improvement over previous solar box cookers and the cooking power make it possible to cook several rations of food in the DG solar oven, rendering it suitable for use in dining rooms in developing countries.

ACKNOWLEDGEMENTS

Thanks to Daniel Orduna, Leonardo Cavagnaro and Pablo Miralles for his help with thermal tests, to Nelly Horak for assisting with the English version. To the National Agency for Scientific and Technological Promotion (ANPCYT) that has partially financed this research.

REFERENCES

Ekechukwu O.V. and N. T. Ugwuoke. (2003). Design and measured performance of a plane reflector augmented box-type solar-energy cooker. *Renewable Energy*. 28: 1935-1952.

El-Sebaii A.A. and A. Ibrahim. (2005). Experimental testing of a box-type solar cooker using the standard procedure of cooking power. Renewable Energy 30(12): 1861–1871.

Esteves A. (2003). Protocolo de Ensayos de Cocinas Solares. In: Cocinas Solares de Iberoamérica CYTED, ed. A. Esteves and R. Román, chapter 5. Salta, Argentina: INENCO.

Esteves A., A. Pattini, A. Mesa, R. Candia and M. Delugan. (1999). Sustainable development of isolated communities and the role of solar technology: the case of Ñacuñan, Santa Rosa, Mendoza, Argentine. In Ecosystems and Sustainable Development II, ed. J.L. Usó and C.A. Brebbia, 235-244. Southampton, Boston: Witpress.

Esteves A., F. Buenanueva, L. Cavagnaro and P.Miralles (2006). Horno solar con ganancia superior e inferior. Evaluación del rendimiento térmico. Avances en Energías Renovables y Medio Ambiente AVERMA 10: 03.87- 03.82.

ACCEPTED MANUSCRIPT

Franco J., C. Cadena and L. Saravia. (2004). Multiple use communal solar cookers. Solar Energy 77: 217-223.

Funk P.A. (2000). Evaluating the international standard procedure for testing solar cookers and reporting performance. Solar Energy 68(1): 1-7.

Khalifa A.M., M.M.A. Taha and M. Akyurt. (1987). Design, simulation and testing of a new concentrating type solar cooker. Solar Energy 38(2): 79-88.

Kurt Hüseyin, Emrah Deniz, and Ziyaddin Recebli (2009). An investigation into the effects of box geometries on the thermal performance of solar cookers. International Journal of Green Energy 5: 508–519.

Mercado M.V. and A. Esteves. (2004). Tecnologías para la conservación de energía en cocción de alimentos. Caja caliente para comedores comunitarios y/o escuelas rurales. Avances en Energías Renovables y Medio Ambiente 8(2): 07-55 – 07.60.

Nahar N.M. (2001). Design, development and testing of a double reflector hot box solar cooker with a transparent insulation material. Renewable Energy 23: 167-179.

Nandwani S.S. (1993). La Cocina u Horno Solar- ¡Hágala Usted mismo!. 1ª ed. Costa Rica: Fundación Universidad Nacional (FUNA).

Nandwani S.S. (2007). Design, construction and study of a hybrid solar food processor in the climate of Costa Rica. Renewable Energy 32: 427-441.

Öztürk H.H. (2004). Second Law Analysis for Solar Cookers. International Journal of Green Energy. Vol. 1 (2): 227-239.

Quiroga M.A. and L. Saravia. (2004). Simulación de Cocina Solar tipo Caja. Msc Thesis in Renewable Energy. August, 42-43. National University of Salta. Argentine.

Schwarzer K. and M. E. Vieira da Silva. (2003). Solar cooking system with or without heat storage for families and institutions. Solar Energy 75: 35-41.

ACCEPTED MANUSCRIPT

Serrano P. and M. Collares Pereira. (2003). Casos de Producción en serie de cocinas solares, In: Cocinas Solares de Iberoamérica CYTED, ed. A. Esteves and R. Román, chapter 10. Salta, Argentina: INENCO.

Shukla S.K. (2009). Comparison of energy and exergy efficiency of community and domestic type parabolic solar cookers. International Journal of Green Energy 6: 437–449.

Sindelar A. and J. Radabaugh. (2008). Retained Heat Cooking Available. The Solar Cooking Archive. http://solarcooking.org/heat-retention/ret-heat.htm (accessed November 13, 2011).

ACCEPTED MANUSCRIPT

Table 1 Absorber temperature and climatic conditions during the no-load test.

N° reflectors	Absober Temperature [ºC]	Ambient Temperature [ºC]		Solar Radiation [W/m^2]	
	Maximum	Maximum	Minimum	Maximum	Minimum
3 reflectors	142.2	30.3	24.4	631.5	481.4
6 reflectors	179.4	27.5	24.8	559.4	471.3
9 reflectors	185.2	26.3	22.1	569.5	528.1
Nandwani oven	132.8	30.3	24.4	631.5	481.4

ACCEPTED MANUSCRIPT

Table 2 Climate data during the thermal power test

N° reflectors	**Temperatura [ºC]**		**Solar Radiation [W/m^2]**	
	Max	**Min**	**Max**	**Min**
3 reflectors	24.8	18.7	786	621
6 reflectors	19.4	14.6	839	719
9 reflectors	23.6	18.9	792	590
Nandwani oven	33.6	26.0	981	739

ACCEPTED MANUSCRIPT

Table 3 Time, absorber temperatures and cooking power with a load of 6 kg of water

Characteristics	**DG Solar Oven**			**Nandwani**
	with 9 refl.	**with 6 refl.**	**with 3 refl.**	**Oven ***
Time from 40ºC to 90ºC; [minutes]	67.5	87.5	107.5	121.0
Time from 40ºC to boil; [minutes]	86.5	107.5	132.5	----
Power for tw – ta = 50ºC [W]	299.2	259.5	192.7	64.5
Thermal efficiency for tw – ta = 50ºC [%]	26.3 %	24.3 %	27.3 %	----

* 3.6 kg as a water mass [3]

Fig. 1. Nandwani Solar Oven with one upper window and reflector.

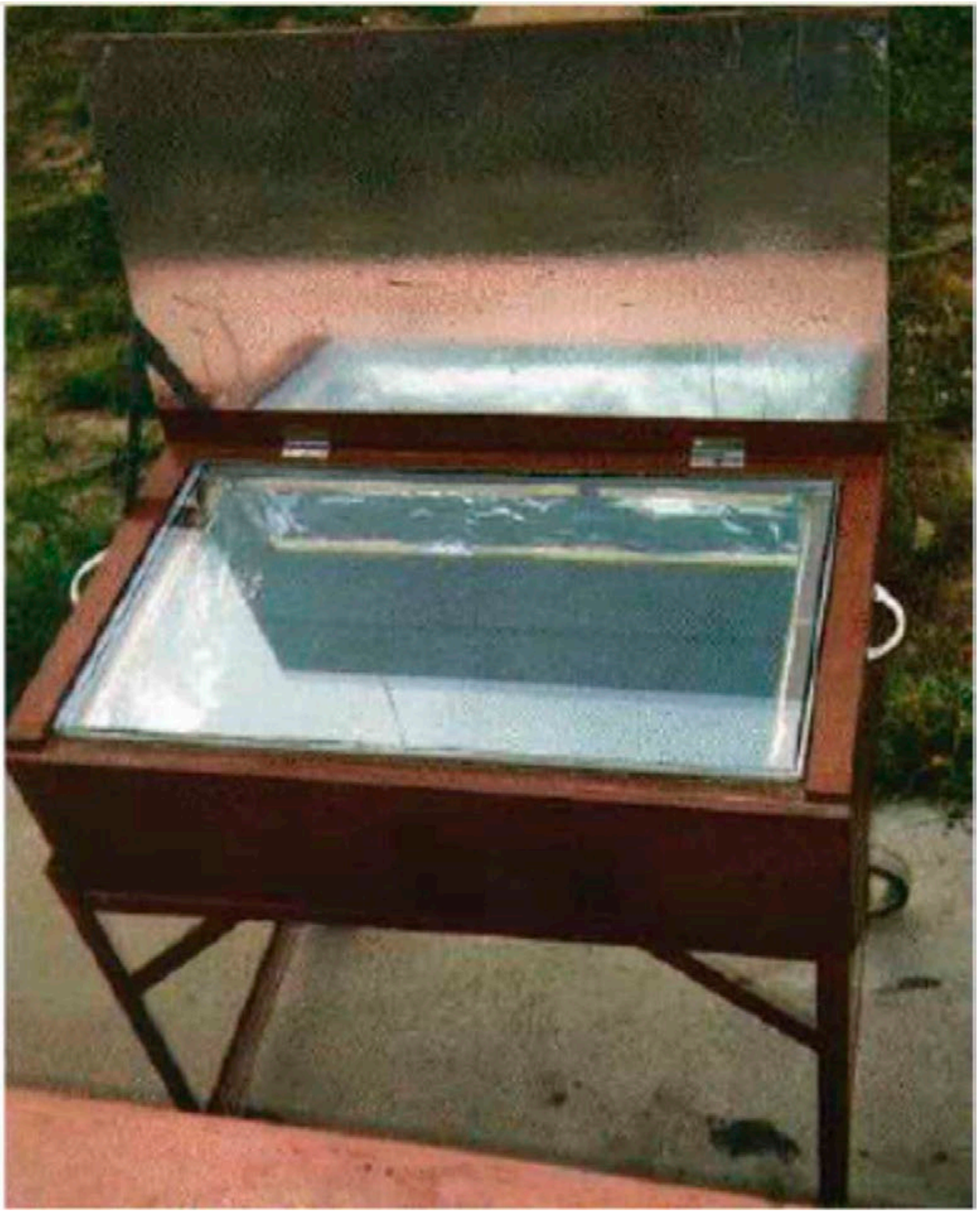

Fig. 2. Solar Restaurant in Villaseca, IV Region, Chile

Fig. 3a. Schematic design of solar oven with upward solar gain.

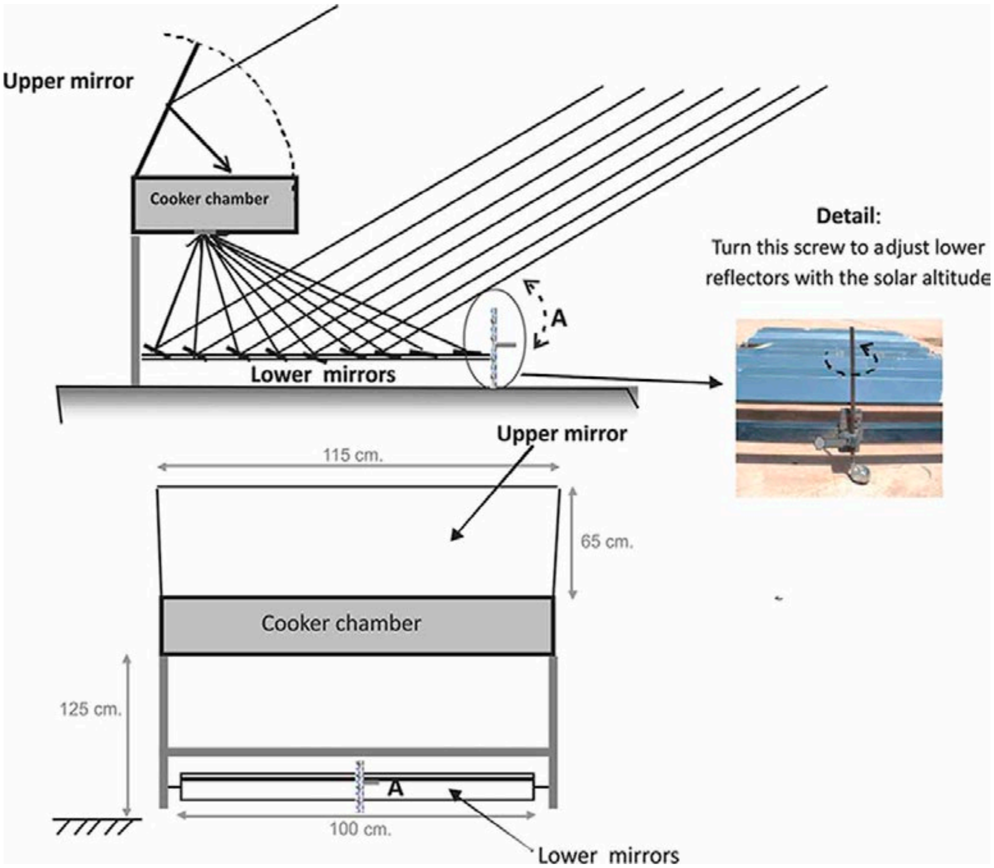

Fig. 3b. Cross-section of the cooker chamber with two windows, upper and lower, door and absorber plate.

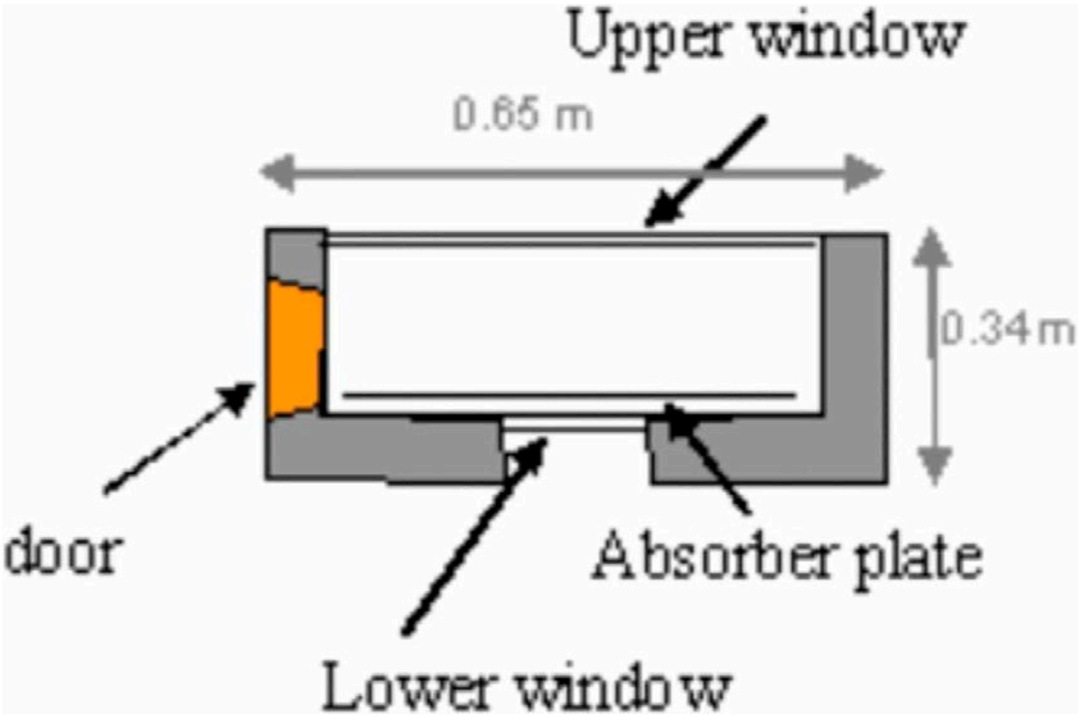

Fig. 4. Double gain solar oven.

Fig. 5. Lower window with Fresnel reflectors in work position.

Fig. 6. Transient diurnal performance of solar oven (with a different number of reflectors)

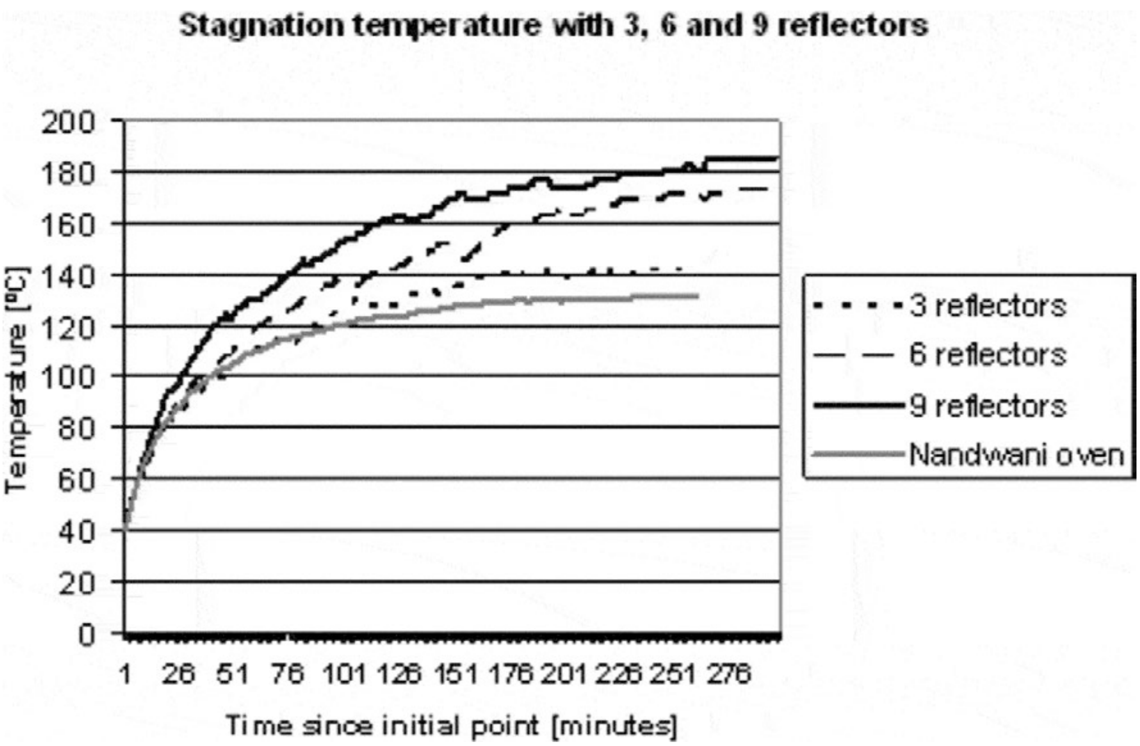

Fig. 7. Water temperature, solar radiation and ambient temperature of each solar oven with 3, 6 and 9 lower reflectors and thermal power vs. Tw-Ta differences for each oven.

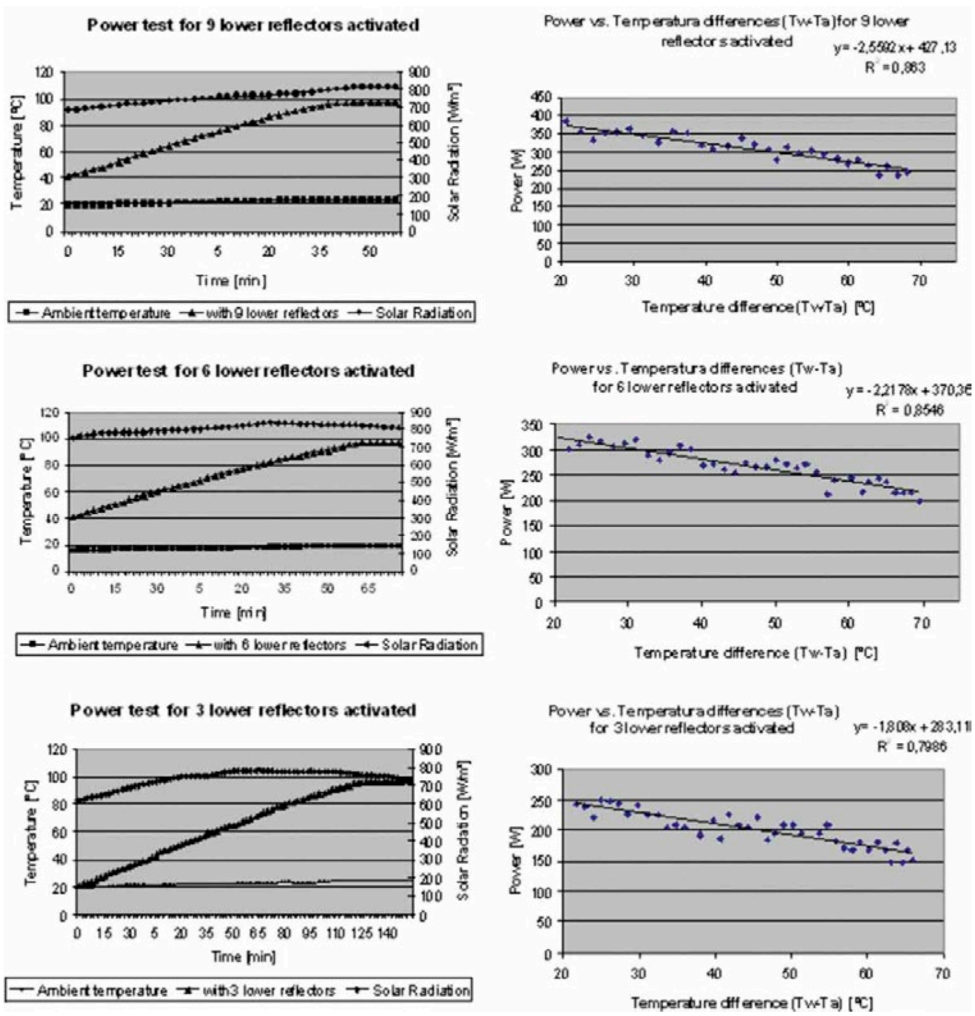

Fig. 8. Frequency of cooking method utilized in dining rooms in Argentina.

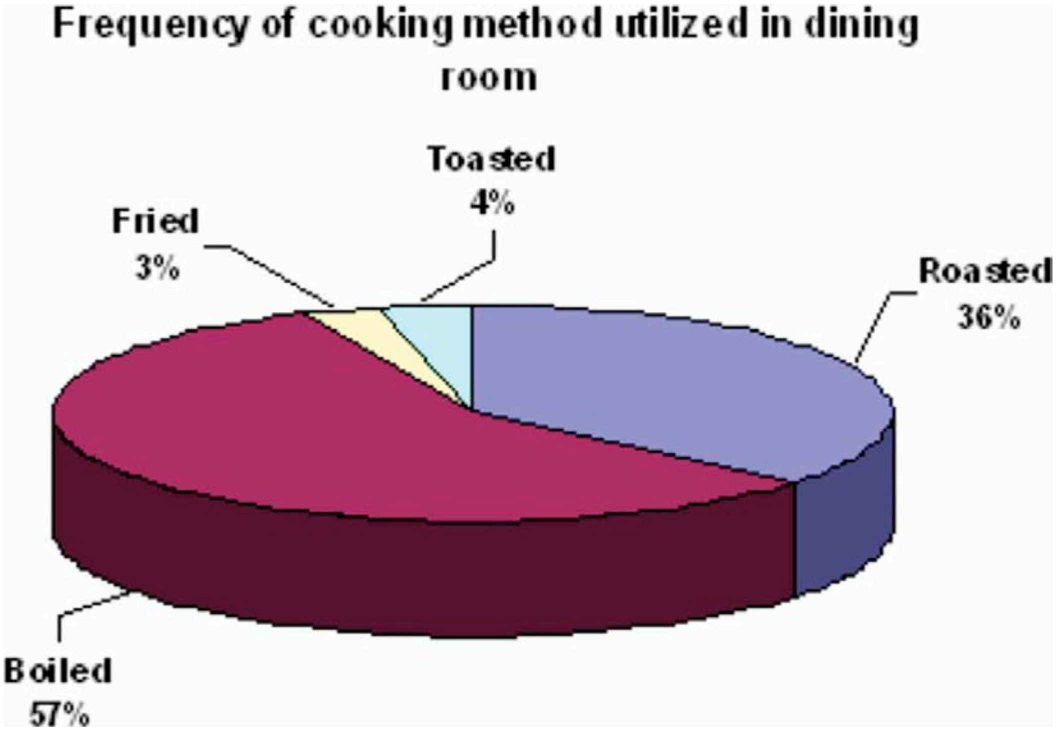

Fig. 9. Whole piece of roast goat meat (9.a) and some bread (9.b) in DG Solar Oven